# PATENT SPECIFICATION

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(19) THE PATENT OFFICE LONDON

## (54) A METHOD AND APPARATUS FOR REDUCING ATMOSPHERIC POLLUTION

(71) We, GILBERT SHAW LIMITED, a British company, of Smith Drive, Campbeltown, Argyll, Scotland, do hereby declare the invention, for which we pray

of combustion of internal combustion engines as described is a most desirable means of reducing cloud formation and permitting freer dispersion of other aerosols into the atmos-

### ERRATUM

SPECIFICATION No. 1,377,501

Page 1, Heading, (21) Application No. *for* No. *read* Nos. *after* 1143/71 *insert* and 44366/71

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*13th October, 1975*

quently.

When aerosol clouds form over urban areas more poisonous pollutants from internal combustion engines and other sources are trapped between them and the earth. Many of these pollutants form nuclei for droplet formation below the cloud level and the visibility and air quality decrease until eventually "smog" is formed.

Known pollutants such as unburned hydrocarbons, sulphur dioxide, carbon, lead, nitrogen and acid compounds build up and eye and respiration irritations follow. The classic smog in London in 1952 in which it is estimated that 4,000 people lost their lives through causes attributable to smog is illustrative of the dangers that urban areas are exposed to. Of course, London has lessened its smog problem by conversion to smokeless fuel but automobile exhausts remain an equally dangerous source of smog trouble. Minimization of aerosols formed from water

... gases. In none of these instances is it recognized that the size of the holding tank required in such a system to dissipate the accumulative heat would be entirely too large for use in automobiles or vehicles. Other patents, for example U.S. Patent No. 3,449,907 and Swiss Patent No. 456,248, are illustrative of recirculating condensate cooling supplemented by ambient air cooling of the condensate in the circulating cycle. Such processes do not properly appreciate the great ambient air cooling surface that would be required by such supplementary air cooling heat exchangers.

Various individual approaches have been taken. British Patent No. 1,160,388 describes the cooling of exhaust gases with subsequent condensation by expansion or adiabatic means although data is lacking concerning the effectiveness of this means. U.S. Patent No. 2,591,187 restricts itself to condensing a limited part of the water of combustion in exhaust gases sufficient to provide radiator

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## (54) A METHOD AND APPARATUS FOR REDUCING ATMOSPHERIC POLLUTION

(71) We, GILBERT SHAW LIMITED, a British company, of Smith Drive, Campbeltown, Argyll, Scotland, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a new and simplified process for reducing atmospheric pollution. It relates particularly to the reduction of air pollution caused by gases and particulate matter emitted from vehicles having internal combustion engines.

Uncondensed water of combustion vapour presently emitted is lighter than air in the ratio of 18 to 29, and rises. In certain instances, where there is low wind velocity with minimum air mixing, the water of combustion will condense as liquid droplets on solid aerosol nuclei and perhaps form ice particles as it rises. In other instances it will form droplets on nuclei at humidities as low as 75% and little free water will be available to form a condensed droplet cloud cover. Such an occurrence happens in Los Angeles frequently.

When aerosol clouds form over urban areas more poisonous pollutants from internal combustion engines and other sources are trapped between them and the earth. Many of these pollutants form nuclei for droplet formation below the cloud level and the visibility and air quality decrease until eventually "smog" is formed.

Known pollutants such as unburned hydrocarbons, sulphur dioxide, carbon, lead, nitrogen and acid compounds build up and eye and respiration irritations follow. The classic smog in London in 1952 in which it is estimated that 4,000 people lost their lives through causes attributable to smog is illustrative of the dangers that urban areas are exposed to. Of course, London has lessened its smog problem by conversion to smokeless fuel but automobile exhausts remain an equally dangerous source of smog trouble. Minimization of aerosols formed from water of combustion of internal combustion engines as described is a most desirable means of reducing cloud formation and permitting freer dispersion of other aerosols into the atmosphere. It should be recognized that condensation of each pound of water releases about 1000 BTU so that temperature inversions over urban areas are certainly caused in part by condensing water of combustion.

The undesirable nature of combustion products emitted from the internal combustion engines of automobiles and other vehicles has been generally recognized at least since 1908 (see for example German Patent No. 228,899). Since that time the problem has prompted many approaches to solving it and a considerable body of art has grown around scrubbing the exhaust gases with re-circulated water of combustion condensate with means for draining same.

Certain disclosures, namely, British Patent Nos. 725,419 and 509,808, Dutch Patent No. 7101634, and French Patent No. 1,467,252, are concerned with holding tanks from which condensate is re-circulated to effect cooling of the exhaust gases. In none of these instances is it recognized that the size of the holding tank required in such a system to dissipate the accumulative heat would be entirely too large for use in automobiles or vehicles. Other patents, for example U.S. Patent No. 3,449,907 and Swiss Patent No. 456,248, are illustrative of recirculating condensate cooling supplemented by ambient air cooling of the condensate in the circulating cycle. Such processes do not properly appreciate the great ambient air cooling surface that would be required by such supplementary air cooling heat exchangers.

Various individual approaches have been taken. British Patent No. 1,160,388 describes the cooling of exhaust gases with subsequent condensation by expansion or adiabatic means although data is lacking concerning the effectiveness of this means. U.S. Patent No. 2,591,187 restricts itself to condensing a limited part of the water of combustion in exhaust gases sufficient to provide radiator



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make-up water. U.S. Patent No. 2,966,036 utilizes high compression and holding action to effect water and combustion product condensation in a holding tank. It fails to recognize that normal cooling of the exhaust gases by ambient air in a heat exchanger can sufficiently condense these elements. U.S. Patent No. 2,487,176 similarly introduces unnecessary elements into the goal of condensing contained water of combustion in automobile and other vehicle exhaust gases. No data pertains to the effectiveness of the first pre-cooler. In U.S. Patent No. 2,612,745 the heat and material content of vehicle exhaust gas does not seem to be appreciated. In the embodiment shown, water from the radiator rises through the condenser and is recycled into the radiator. The fact that the entry temperature of discharged radiator water may be in the order of 115° to 120°F and the fact that the dew point of automobile exhaust gas is in the order of 127°F suggest that little condensation is attained. In the absence of definitive data it can only be assumed that alternative cooling systems suggested by this patent may have similar shortcomings. German Patent No. 226,899 seems to make no provision for control of the water of combustion quantities discharged to the atmosphere and German Patent No. 1,918,421 depends upon a combination of a convection cooling surface and an expansion chamber followed by screening of the resultant condensate.

The invention recognizes that water as water of combustion in exhaust gases from the vehicular internal combustion engines is a primary air pollutant when it condenses to form water droplet or ice particle aerosols as it rises in the atmosphere and the invention has as a primary object provision of a simplified process for reducing the frequency of air-borne water of combustion droplets or ice particles whereby the amount of water available for water droplet or ice particle formation is reduced.

Another object of the invention is to reduce the content of generally recognized air pollutants such as sulphur oxides, nitrogen derivatives, hydrocarbons, particulate matter, lead, and acids in gases formed by vehicular engines as a result of the scrubbing or washing action effected by the water of combustion as it condenses. Such pollutants constitute nuclei on which air-borne water of combustion forms aerosols.

A further important object of the invention is to reduce smog over urban centres.

According to the present invention there is provided a process for removing water of combustion and condensation nuclei of pollutant nature from exhaust gases emitted from vehicular internal combustion engines such as those used in automobiles comprising cooling the vehicle exhaust gases to a temperature in the range between the dew point temperature of the contained water of combustion and the ambient temperature of the air surrounding the vehicle using said surrounding air as the coolant for a heat exchanger in which a substantial percentage of the contained water of combustion is condensed; entrapping condensation nuclei normally present in vehicle exhaust gases in the condensed water of combustion as a result of the washing action of same; separating the condensed water of combustion and condensation nuclei mixture from the residual non-condensed exhaust gas; storing the water of combustion and the condensation nuclei entrapped therein in a receptacle for subsequent removal; and reheating the residual exhaust gas from which a large percentage of the initial water of combustion has been removed and a positive reduction of the initial aerosol-forming nuclei content has been made to tend to prevent formation of an undesirable cooled exhaust gas blanket at road level.

According to a further aspect of the present invention there is provided an apparatus for removing water of combustion and condensation nuclei of pollutant nature from exhaust gases emitted from vehicular internal combustion engines such as those used in automobiles comprising a heat exchanger for cooling the vehicle exhaust gases to a temperature in the range between the dew point temperature of the contained water of combustion and the ambient temperature of the air surrounding the vehicle using said surrounding air as the coolant so as to condense a substantial percentage of the contained water of combustion while entrapping condensation nuclei normally present in vehicle exhaust gases in the condensed water of combustion as a result of the washing action of same; means for separating the condensed water of combustion and condensation nuclei mixture from the residual non-condensed exhaust gas; means for storing the water of combustion and the condensation nuclei entrapped therein for subsequent removal; and means for reheating the residual exhaust gas from which a substantial percentage of the initial water of combustion has been removed and a positive reduction of the initial condensation nuclei content has been made to tend to prevent formation of an undesirable cooled exhaust gas blanket at road level.

Preferably also, means are provided for storing the condensed water of combustion under conditions which prevent the freezing thereof.

It is desirable to cool the exhaust gases as close as possible to the ambient air temperature to cause as much condensation as possible and subsequently entrap the considerable water of combustion condensation before emission of the residual combustion gases to the atmosphere.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying diagrammatic drawings in which:—

Fig. 1 is a top plan view of one form of heat exchanger for incorporation in an automobile;

Fig. 2 is an end view of the heat exchanger of Fig. 1 showing it connected to a condensate receptacle;

Fig. 3 is a top plan view of a second form of heat exchanger for incorporation in an automobile; and

Fig. 4 is a front end view of the arrangement shown in Fig. 3.

Referring in detail to a first embodiment of the invention, Figs. 1 and 2 illustrate a heat exchanger including hollow cooling plates which are used to air cool the exhaust gas from a vehicle below the dew-point of the exhaust gas. The plates may be located as desired as part of the automobile. Other forms of thermal cooling can be used.

Fig. 1 shows the top view of such a hollow plate which consists of two formed 24 gauge 104 stainless steel sheets $\frac{3}{8}''$ apart and welded at the edges 2. The sheets are also welded together along a family of lines as at 3 to give a serpentine path between an exhaust gas inlet connection 5 and cooled exhaust gas exit 6, said inlet and exit connections 5 and 6 being welded to the hollow plate 1. Additionally, the two sheets are spot formed and spot welded at spaced intervals as shown by the representative dots designated 4 to give a quilted effect. The overall size of the plates in this embodiment is 28″ by 42″.

Fig. 2 shows an assembly of five plates as in Fig. 1 mounted one above the other and designated 1, 1a, 1b, 1c and 1d the assembly comprising one embodiment of an engine exhaust gas cooling heat exchanger.

In the air cooled heat exchanger shown in Figs. 1 and 2, exhaust gas from the automobile engine enters the inlet 5 as shown by the directional arrow 5a follows the serpentine and quilted path shown in Fig. 1 and exits at 6 through bolted flanges 7 and 9 into plate 1a, a sealing gasket 8 being located between machined flanges 7 and 9. In like manner, the exhaust gas flows in turn through plate 1a, flange 10, gasket 11, flange 12, into plate 1b; through plate 1b into flange 13, gasket 14, and flange 15 into plate 1c; and through plate 1c; flange 16, gasket 17 and flange 18 into plate 1d. The flanges are affixed to the pipe extensions from the plates by means of standard threaded connections.

From plate 1d, the exhaust gas exits through connection 20 into condensate receptacle 19, proceeds through woven wire mesh entrainment separator 21 into emission pipe 22 and as shown by directional arrow 23.

Water of combustion accumulations plus other contaminates pass into receptacle 19 as an unseparated mixture and can then be drained from receptacle 19 through nipple 24 with pipe cap 25 removed or by more sophisticated means.

In the embodiment shown in Figs. 1 and 2 the stainless steel sheet thickness used in the construction of the cooling plates was 0.0224″ but the manufacturer of these cooling plates estimates that 0.008″ plate thickness could be fabricated and that such plates would have twenty pounds per square inch working pressure. The air for cooling the exchanger plates is ambient air drawn in on travel of the vehicle e.g. by scoops and can if desired be forced by means of a fan.

Figs. 3 and 4 illustrate a second preferred form of exhaust gas heat exchanger. In this embodiment plates 30, 30a, 30b, 30c and 30d are placed vertically and parallel to each other so as to be self-draining. The distance between them need only be in the order of one half to one inch, but the spacing distance is optional. Exhaust gas emerging from the vehicle engine through pipe 31 enters a manifold 32 to which the heat exchange plates are attached adjacent their upper edges and into which the heat exchange plates are open. The assembly could be made by welding. The exhaust gas passes in parallel flow for minimum pressure drop through the plates 30—30d to be cooled below their dew-point by ambient air alone and emerges into manifold 34 which is affixed to the various plates in the same manner as manifold 32 but adjacent the lower edges thereof. Manifold 34 discharges into insulated receptacle 36 at 35 and the receptacle is insulated as at 37 e.g. a double wall formation. The uncondensed exhaust gases pass through entrainment separator 38 of the type known as a Demister: passes through pipe 39 into the double pipe secondary heat exchanger 40, located where convenient, in exhaust line 31 and then exhaust gases are emitted through fitting 41 to the atmosphere at a temperature higher than ambient air temperature. The purpose of the double pipe secondary heat exchanger 40 is to heat the exhaust gases sufficiently before discharge to prevent them from forming an undesirable uncondensed exhaust gas blanket at road level. It has been observed that exhaust gas emitted near the ambient air temperature and water saturated tends to show condensation when it exits the vehicle.

The high surface area to volume ratio of the cooling plates as described could be attained by other means. The vertical family of parallel plates 30—30d can be shrouded in a thermostatically controlled housing through which ambient air is moved positively by fan action aided perhaps by air scoop action. Drain plug 42 permits drainage from tank 36 when desired but other more sophisticated means than plugs could be used for this purpose. In general the size of tank 36 would be about the same size as the fuel tank of the vehicle.

Ambient air is supplied to the exchanger plates in the same manner as in the embodiment of Figs. 1 and 2.

In both the embodiments described above with reference to Figs. 1, 2 and Figs. 3, 4 the water condensate receptacle or tank 19 and 36 respectively can be insulated in any of various ways in order to protect the contents thereof against freezing. For example the receptacle can be formed with spaced double walls similar to a Dewar flask arrangement.

In both the embodiments described above in relation to the drawings, the exhaust gases are carried through the heat exchangers with little decrease in the speed of flow so that solid particles are prevented as far as possible from being deposited in the interior of the exchangers.

Petrol or gasoline burned in automobile engines is frequently designated as its major constituent, hexane, or $C_6H_{14}$, although as a general rule the weight of petrol runs higher than the 5.5 lbs. per gallon that would represent hexane. For a physical explanation of the behaviour of automobile exhaust gases consideration of petrol as being hexane will suffice. Diesel fuel or propane fuel would be differently represented but the combustion by-products would be of similar nature.

During the combustion of hexane the following chemical equation theoretically occurs

$$C_6H_{14}+9.5O_2+35.7N_2=6CO_2+7H_2O+35.7N_2$$

where the nitrogen to oxygen ratio is as in air, i.e., 79:21, and other small amounts of other inert gases are considered to be nitrogen. The letter designations in the foregoing chemical formula are:

| Symbol | Name | Pounds per Pound Molecular Weight |
|---|---|---|
| C | =Carbon | =12 |
| $H_2$ | =Hydrogen | = 2 |
| $O_2$ | =Oxygen | =32 |
| $N_2$ | =Nitrogen | =28 |
| $CO_2$ | =Carbon Dioxide | =44 |
| $H_2O$ | =Water | =18 |
| $C_6H_{14}$ | =Hexane | =86 |

For each 86 pound molecular weight of hexane burned, 7 pound molecular weights or $7\times18=126$ pounds of water and 6 pound molecular weights of carbon dioxide, or $6\times44=264$ lbs., theoretically are produced. Additionally, 35.7 lb. molecular weights of nitrogen, or $35.7\times28=1000$ lbs., would remain substantially unchanged during the combustion of the hexane. The ratio of water to dry gas in the combustion products would then be:

$$\frac{126}{264+1000}=0.1$$

In order to have a humidity of 0.1 lbs. of water vapour per pound of dry air, according to standard humidity charts air would have to be saturated at about 127°F. but because the density of automobile exhaust gas is somewhat higher than that of air and oxidation would not be perfect, exhaust gas would have a somewhat different saturation temperature than that indicated for air.

However, continued cooling of exhaust gas below its dew-point and in the direction of ambient air temperature would result in condensation of an increasingly larger quantity of water of combustion. Other hydrogen bearing fuels would similarly produce water in varying degrees.

For example, passing the exhaust gas from a 1958 Hillman Minx through a stationary test rig, namely, 150 feet of atmospheric air-cooled 1¼" I. D. iron tubing fashioned in a serpentine manner followed by a condensate receptacle and a woven wire entrainment separator of conventional design sold under the trade name Demister between the condensate receptacle and final emission exit pipe resulted in the average recovery of 993 cc of condensate from 2350 cc of petrol in six test runs. This is equivalent to a volume of water recovered to volume of petrol burned ratio of 42.2%, a most appreciable figure. In the instance of the embodiment shown in Figs. 1 and 2, the volume of water to petrol burned ratio was found to average 51.5% in three test runs. These figures would represent respectively 64.2% and 78.2% by weight of the contained water of combustion again assuming that the fuel may be considered as being hexane.

In making the above engine tests for both the test rig and the embodiment of Figs. 1 and 2, it was found that a burst of high engine speed for a short period during which 100—150 cc of petrol was consumed, cleared the heat exchangers of residual condensate, and the heat exchangers were blasted in this manner prior to and at the end of each engine run. In the tubing heat exchanger of the test rig, the tubing heat exchanger, condensate trap, and entrainment separator were mounted alongside the test automobile. The embodiment as shown in Figs. 1 and 2 was road tested when located in the boot or trunk of the aforesaid Hillman Minx.

The exhaust gas temperature upon emission from the 150 foot 1¼" I. D. air-cooled sepentine heat exchanger averaged 81°F, and the average outdoor temperature was 49°F. With a known exhaust gas temperature of 1400°F. at the engine it was possible to calculate the overall amount of heat removed by the heat exchanger. Using this figure, the surface area of the heat exchanger, and the average temperature difference between ambient air and the inlet and outlet temperatures, an overall heat transfer coefficient of 1.4 BTU per pound of exhaust gas per degree F. per square foot was obtained. This figure appears to be reasonable in light of the various assumptions made and the reported overall heat transfer coefficient range for gas to gas in free convection of 0.6 to 2 (John H. Perry's Chemical Engineering Handbook, page 481) and the overall heat transfer coefficient of 1—3 given for condensing vapour to gas with free convection in the same reference. Were the exhaust gases to be cooled to 59°F., 10°F. higher than the ambient air temperature, in the serpentine tubing of the test rig, considerably more cooling surface would be required if the overall heat transfer coefficient of 1.4 mentioned above were to be used. However, the presence of a considerable quantity of condensate would increase the overall coefficient and reduce the additional cooling surface that would be required to cool the exhaust gas to 10°F. above the ambient air temperature.

In the event exhaust gases were to be cooled to within 10°F. of the ambient air temperature with cooled condensate from a storage tank, the heat to be dissipated from the condensate tank using the same heat transfer coefficient of 1.4 would require a huge condensate storage tank, which, according to the German Patent No. 226,899, weight and size-wise is not feasible for use in motor vehicles.

Similarly if an ambient air cooler were to supplement cooling of re-cycled condensate, the exterior air film on the heat exchanger would still be the major block to heat transfer to the ambient air, so that generally the same heat transfer area would be required for the removal of each BTU with or without the re-circulation.

Various standard engineering practices could be applied to increase the overall heat transfer coefficient and permit cooling of the exhaust gas to within 10°F. of ambient air temperature. For example, forced convection cooling, as with a fan, of the external plate surfaces of Figs. 1 to 4 would immediately increase the heat transfer coefficient to the range of 2 to 10 (Perry reference cited).

As stated previously in relation to the embodiment of Figs. 3 and 4, it is preferable to arrange the cooling plates so that they are parallel in a vertical position to permit complete self-draining of the exhaust gas-ambient air heat exchanger. In such position the inside surfaces of the heat exchanger would tend to be coated with a continuous liquid film rather than possibly the drop type condensation that might be characteristic of the embodiment illustrated by Figs. 1 and 2 and heat transfer would be improved as a result. Since the limiting heat transfer factor for overall heat transfer is the air film on the external surface of the plates, fins could be advantageously used to increase the external surface area. Within the heat exchanger the use of an impinger located in the exhaust gas train seemed to assist coalescence of the condensate droplets, thereby rendering recovery of the condensed water of combustion more efficient. By incorporation of these customary engineering practices, it should be possible to obtain an overall heat transfer coefficient of 5. With such a coefficient the surface required to cool the exhaust gases to 81°F. would be very much less for each of the embodiments described. The additional area required to cool the exhaust gases further to within 10°F. of the ambient air temperature would also be much less.

Water of combustion recovery will vary with the humidity of the air used in combustion. Under the extreme condition of nil ambient air humidity, when exhaust gas is cooled solely by convection as described to 50°F., condensation will approximate 92% of the contained water of combustion. Similarly, in hotter weather, when exhaust gas can be cooled only to approximate 100°F., the degree of condensation of the water of combustion will still be 57%. Further, engineering practice recognizes that, for example, installation of a spring loaded valve as at 22 in line 23 of Figs. 1 and 2 operating to release the cooled exhaust gas at 14.7 lbs. per square inch gauge, said pressure being generated in or by the vehicle engine, would halve the amount of uncondensed water of combustion as compared to the uncondensed water left under the essentially atmospheric pressure utilized in arriving at the 92% and 57% condensation figures mentioned.

Chemical analysis conducted at Strathclyde University in Glasgow showed that effective removal of sulphur dioxide was accomplished by the water of combustion as it condenses. Exhaust gas analysis for sulphur dioxide was effected by drawing 30 litres of cooled exhaust gas through a sodium peroxide solution to oxidize the sulphur oxide to sulphate which was then precipitated as barium sulphate and weighed. The exhaust gas showed a sulphur dioxide content of only 0.0004%.

The exhaust gas cooling embodiment shown in Figs. 1 and 2 gave water of combustion condensate containing the following:

| | Test A | Test B |
|---|---|---|
| Solids Analysis: | | |
| Weight % of solids | 0.019 | 0.025 |
| Carbon, % | 0.019 | 0.025 |
| Liquid Analysis: | | |
| pH | 3 | 3.2 |
| % Iron | 0.0024 | 0.0027 |
| % Sulphur | 0.0015 | 0.0010 |
| % Lead | 0.035 | 0.042 |
| % Organics | 0.050 | 0.033 |
| % Chloride | 0.030 | 0.034 |
| % Nitrite | positive | positive |

It can be seen from the foregoing that the recovered water of combustion was acidic in nature and had in the process of condensing and entrapment scrubbed out other materials that are recognized air pollutants and possible nuclei for smog or fog condensation.

Condensate from the previously described serpentine iron pipe exhaust cooler of the test rig, while less acidic, i.e. 4.6 pH, showed the same general scrubbing effectiveness.

The test methods used were:

Solids Analysis:

Solids: The sample was filtered and the solids were washed with water and dried to constant weight at 105°C.

Carbon (Particulate Matter): The dried sediment was dispersed in 50% nitric acid and the solution filtered. The residue was washed, dried to 105°C. and weighed. That part burned off at 600°C. leaving no residue was assumed to be carbon.

Liquids Analysis:

pH: The acidity readings were made by instrument and confirmed by treatment with 1M sodium hydroxide.

Iron: The concentration of iron ($Fe^{++}$) present in the filtrate was determined by oxidation followed by precipitation as feric hydroxide using ammonium hydroxide, the precipitate being filtered and ignited to constant weight at 800°C.

Sulphur: Recovered and filtered water of combustion sulphate content was measured by the precipitate formed in filtrate following the addition of barium chloride in hydrochloric acid solution.

Lead: Determinations were made by means of atomic absorption spectrophotometry.

Hydrocarbons (Organics): After filtering, the water of combustion was treated with nitric acid and extracted with chloroform and the chloroform then was evaporated. Gas chromatographic examination of the extract suggested the presence of a mixture containing 10 to 12 components. Infrared examination gave a broad band between 3300—3500 $cm^{-1}$; three separate peaks at 2860, 2930, and 2970 $cm^{-1}$: and a group of seven peaks at 1270, 1390, 1410, 1460, 1605, 1700 and 1700 $cm^{-1}$.

Chlorides: Determinations were made by precipitating same with silver nitrate in nitric acid followed by customary weighing procedure.

Nitrites: The filtered water of combustion was boiled with sodium hydroxide and Devarda's alloy and a faint trace of ammonia turned red litmus paper blue in the mouth of the test tube. Thus, a trace of nitrite or nitrate is present in the water of combustion. A very sensitive test for nitrite involving formation of a diazonium compound with sulphanilamide and coupling with N - 1 - (1 - napthyl)ethylene - diamine hydrochloride gave a positive test for nitrite.

It was noted that an internal scale formed in the first few feet of the test rig automobile exhaust pipe, said scale having a high lead and carbon content. On one occasion sediment in the water of combustion condensate showed a 2.7% lead content. Other sediment samples showed nil content. The exception was attributed to break-off of the before mentioned internal scale.

The pollutants that have been discussed above are presently removed from the atmosphere by rain or snow and the acidic elements contained therein have been widely recognized for their destructive effect on statuary, vegetable matter and animal well being. In the process of this invention the rain purifying operation as it pertains to internal combustion engines is effected within the exhaust system using condensed water of combustion as the cleansing medium.

While small amounts of oxalates could have been present in the water through the interaction of carbon monoxide, carbon dioxide and water, it would appear that carbon monoxide is mainly carried out in the exhaust gas after cooling. Analysis showed such exhaust to contain 4.4% carbon monoxide as measured by absorption in ammoniacal cuprous chloride and confirmed by infra-red absorption analysis. New vehicles would of course have a lower carbon monoxide emission but any emission would be bad if cooled exhaust gas formed a blanket at road level.

Although poisonous in itself, carbon monoxide concentration in the atmosphere has not increased over the years that internal combustion engine emissions have been a matter of concern. It has been reported that carbon monoxide emitted to the atmosphere is purged out every fourteen days.

Being lighter than air in the ratio of 28 to 28.9 and on the indicated basis that air acts as a perfect gas, carbon monoxide would be expected to rise in the atmosphere in the same manner as water vapour especially if given the impetus of heating prior to emission. Subsequently complex chemical reactions seem to alter the carbon monoxide, presumably to carbon dioxide.

It is envisaged that accumulated water of combustion condensate plus other pollutants would be drained from the exhaust system each time the petrol tank was filled. Such drainings could proceed to a holding tank and be subsequently transferred to a purification station where the condensate could be recovered in pure form for disposal following known purifying practices that could include filtration, biochemical, osmotic or distillation means.

The widely different forms of the exhaust gas coolers described herein, i.e., test rig pipe arranged in serpentine fashion, the plates of Figs. 1 and 2, and those of Figs. 3 and 4, illustrate the point that widely divergent designs could be utilized to achieve the desired objects of this invention. For example, the serpentine pipe was iron whereas the heat exchanger of Figs. 1 and 2 was stainless steel. An electro-plated and corrosion resistant lining could be applied to a heat exchanger equally well. In the two embodiments of the invention tested, the heat exchangers sufficiently silenced the exhaust to preclude the need for a separate silencer or muffler.

WHAT WE CLAIM IS:—

1. A process for removing water of combustion and condensation nuclei of pollutant nature from exhaust gases emitted from vehicular internal combustion engines such as those used in automobiles comprising cooling the vehicle exhaust gases to a temperature in the range between the dew point temperature of the contained water of combustion and the ambient temperature of the air surrounding the vehicle using said surrounding air as the coolant for a heat exchanger in which a substantial percentage of the contained water of combustion is condensed; entrapping condensation nuclei normally present in vehicle exhaust gases in the condensed water of combustion as a result of the washing action of same; separating the condensed water of combustion and condensation nuclei mixture from the residual non-condensed exhaust gas; storing the water of combustion and the condensation nuclei entrapped therein in a receptacle for subsequent removal; and reheating the residual exhaust gas from which a large percentage of the initial water of combustion has been removed and a positive reduction of the initial aerosol-forming nuclei content has been made to tend to prevent formation of an undesirable cooled exhaust gas blanket at road level.

2. A process according to claim 1 wherein the water of combustion is stored under conditions which prevent freezing of the water of combustion.

3. A process according to claim 1 in which the vehicular internal combustion engine exhaust gas is cooled above atmospheric pressure, said pressure being generated in the internal combustion engine and maintained by means of an exhaust gas release valve.

4. An apparatus for removing water of combustion and condensation nuclei of pollutant nature from exhaust gases emitted from vehicular internal combustion engines such as those used in automobiles comprising a heat exchanger for cooling the vehicle exhaust gases to a temperature in the range between the dew point temperature of the contained water of combustion and the ambient temperature of the air surrounding the vehicle using said surrounding air as the coolant so as to condense a substantial percentage of the contained water of combustion while entrapping condensation nuclei normally present in vehicle exhaust gases in the condensed water of combustion as a result of the washing action of same; means for separating the condensed water of combustion and condensation nuclei mixture from the residual non-condensed exhaust gas; means for storing the water of combustion and the condensation nuclei entrapped therein for subsequent removal; and means for reheating the residual exhaust gas from which a substantial percentage of the initial water of combustion has been removed and a positive reduction of the initial condensation nuclei content has been made to tend to prevent formation of an undesirable cooled exhaust gas blanket at road level.

5. Apparatus according to claim 4 in which the means for separating the condensed water of combustion and condensation nuclei mixture from the residual non-condensed exhaust gas includes an entrainment separator.

6. Apparatus as claimed in claim 4, in which the means for re-heating the residual exhaust gases comprises a secondary heat exchanger heated by the hot untreated gases before cooling.

7. Apparatus as claimed in claim 4, in which the storage means for water of combustion is insulated to prevent freezing of the fluid contents thereof.

8. Apparatus as claimed in claim 4, in which the heat exchanger comprises a bank of interconnected hollow plates through each of which the hot exhaust gases are arranged to pass.

9. Apparatus as claimed in claim 4, in which means are provided for maintaining the exhaust gases above atmospheric pressure during cooling thereof in order to increase the yield of condensed water of combustion.

10. Apparatus as claimed in claim 4, in which the storage means is provided with drainage means for enabling removal at desired intervals of the stored water of combustion and pollutants.

11. A process for removing water of combustion and pollutants from the exhaust gases of an internal combustion engine, substantially as hereinbefore described with reference to Figs. 1 and 2 or Figs. 3 and 4 of the accompanying drawings.

12. Apparatus for removing water of combustion and pollutants from the exhaust gases of an internal combustion engine, substantially as hereinbefore described with reference to Figs. 1 and 2 or Figs. 3 and 4 of the accompanying drawings.

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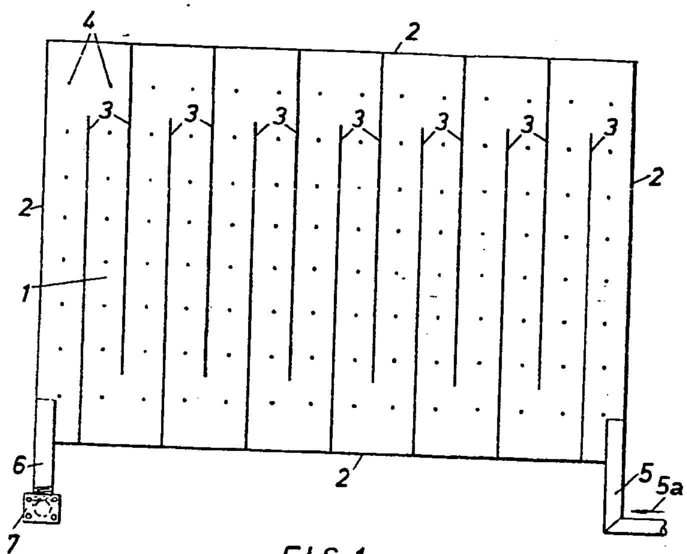
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7
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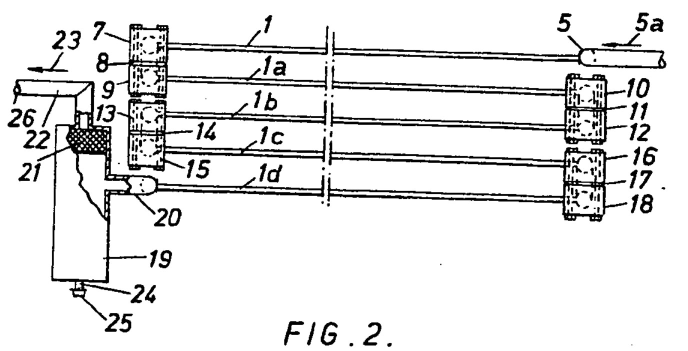
5a

FIG. 1.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22
21
1
1a
1b
1c
1d
14
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19
24
25
5
5a
10
11
12
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17
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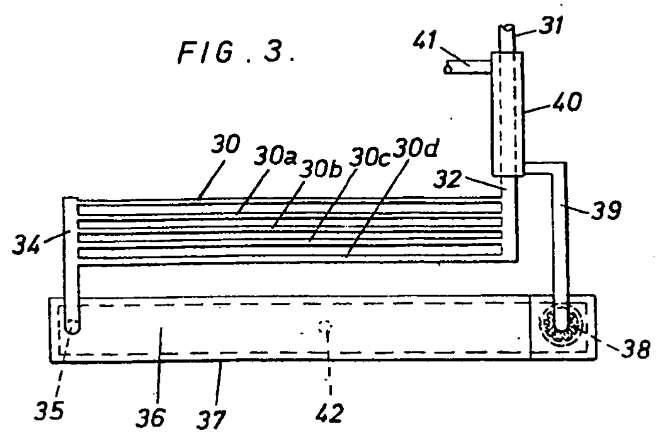
FIG. 2.

FIG. 3.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30a
30b
30c
30d
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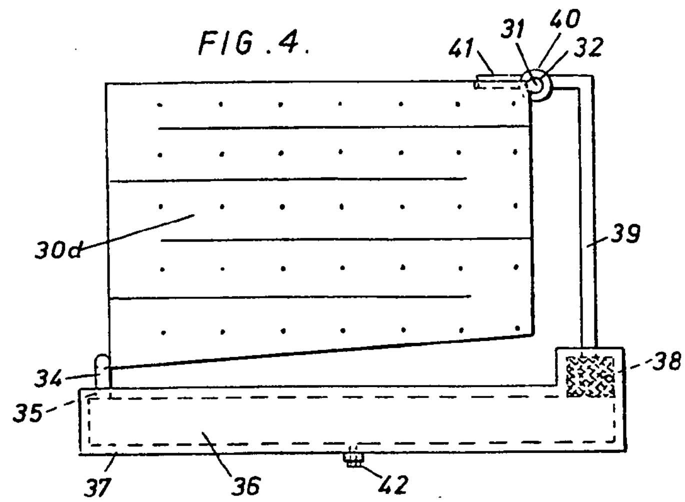
FIG. 4.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